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A Utility-based Priority Scheduling Scheme for Multimedia Delivery over LTE Networks

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Abstract—With the mobile networks migrating towards LTE-Advanced and all-IP networks, people expect to connect to the Internet anytime, anywhere and from any IP-connected device. Moreover, nowadays people tend to spend much of their time consuming multimedia content from various devices with heterogeneous characteristics (e.g., TV screen, laptop, tablet, smartphone, etc.). In order to support uninterrupted, continuous, and smooth video streaming with reduced delay, jitter, and packet loss to their customers, network operators must be able to differentiate between their offerings according to device characteristics, including screen resolution. This paper proposes a novel Utility-based Priority Scheduling (UPS) algorithm which considers device differentiation when supporting high quality delivery of multimedia services over LTE networks. The priority decision is based on device classification, mobile device energy consumption and multimedia stream tolerance to packet loss ratio. Simulation results demonstrate the benefits of the proposed priority-based scheduling algorithm in comparison with two classic approaches.

Index Terms—Long Term Evolution, Scheduling Algorithm, Utility Functions, Quality of Service, Energy Consumption.

I. INTRODUCTION

THE increasing demand for interactive multimedia-based applications, such as video streaming, social networking, live gaming, e-learning, navigation and cloud sync, with strict Quality of Service (QoS) requirements, puts a lot of pressure on the next generation mobile networks [1][2][3][4]. For this purpose, the new Long Term Evolution (LTE) standard which aims at designing the all-IP network architecture, highly improves the spectrum efficiency and significantly reduces the transfer latency. According to the white paper released by Informa Telecom & Media¹, in 2011 there were only 6.4% of LTE deployments all over the world, reaching the highest peak of 34.1% in 2012, while for 2013 there are 25.4% LTE deployments planned [5]. Thus, it is obvious that LTE has been the fastest-growing technology among the 4G standards.

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Utility-based Priority Downlink Scheduling for Multimedia Streams over LTE Networks

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Moreover, with the advances in technologies, mobile computing devices such as smartphones, PDAs, small netbooks, etc. have become more affordable and powerful, mobile users expecting anywhere connectivity, seamless services, and high quality levels. A study reported by Google [6] says that 90% of all media interactions of the users on a daily basis are screen based, meaning that a person spends on average 4.4 hours of the leisure time per day, in front of screens (e.g., smartphone, laptop/PC, tablet, television, etc.). In this context the main challenge that the mobile network operators are facing is the ability to differentiate between the multiscreen offerings in order to provide seamless multimedia experience with minimal delay, jitter, and packet loss, to their customers. An example of a multiscreen diversity scenario within a LTE Network is illustrated in Figure 1.

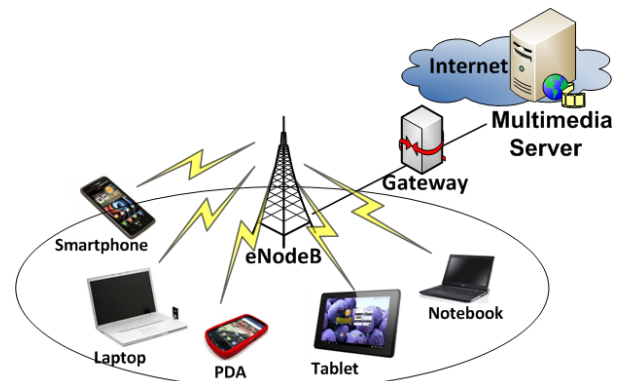


Figure 1. Multiscreen Diversity Scenario within the LTE Network

Because of the popularity of high-performance mobile devices, the scheduling schemes should take into account, apart from the conventional constraints, the mobile device characteristics as well, such as display resolution and battery lifetime.

This paper proposes a novel Utility-based Priority Scheduling (UPS) algorithm for multimedia streaming over LTE networks. The proposed UPS mechanism takes into account the QoS constraints of the multimedia application, the information about the device display resolution and the energy consumption of the mobile device in order to prioritize the resource allocation and ensure the best multimedia experience to the mobile users. The remainder of the paper is structured as follow: Section II summarizes the related work, and a framework of the proposed scheduling mechanism and the detailed procedure of the proposed scheduling algorithm are

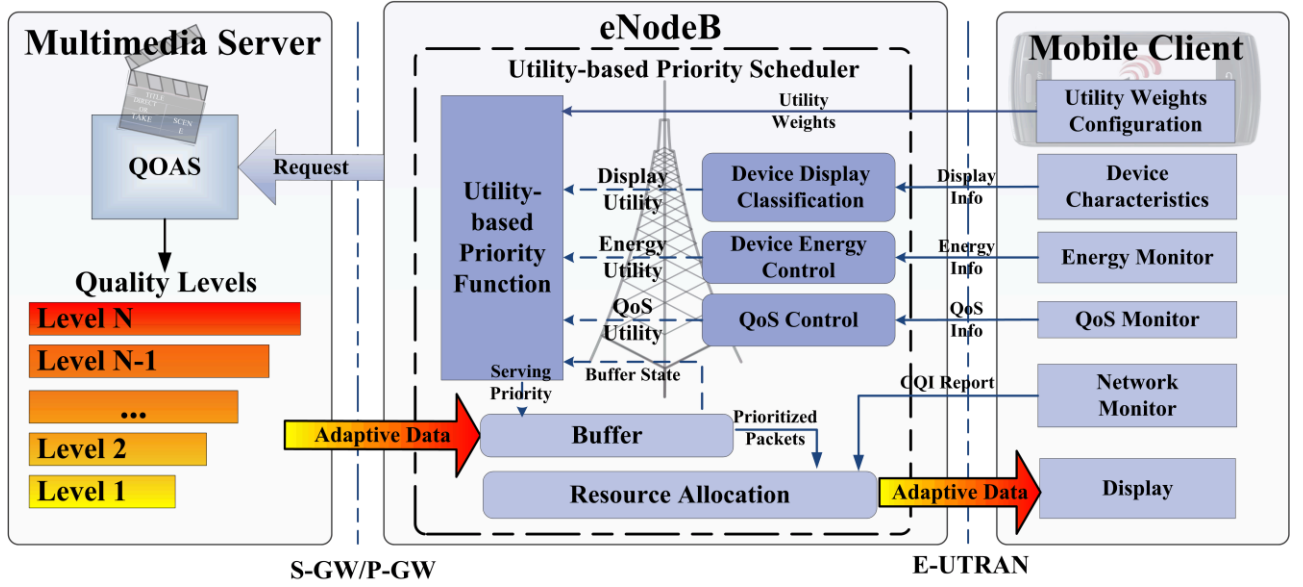


Figure 3. Utility-based Priority Scheduling Mechanism - Framework

described in Section III. The numeric example-based analysis and simulation configuration are presented in Section IV and Section V, respectively. Section VI presents the proposed solution's performance evaluation in comparison with well-known algorithms and conclusions are in Section VII.

II. RELATED WORKS

A very well-known scheduling scheme for OFDM-based systems was proposed by Knopp et al. in [7]. First, the scheme defines the maximum overall rate as the rate allocated to a user with the best channel gain, and then it allocates a higher transmission power to the same user. The authors in [8] look at the downlink scenario with limited dynamic power range, and propose a Maximum Sum Rate (MSR) scheduling scheme without transmission power adaptation. The proposed MSR mechanism is simple and efficient in terms of optimal data traffic scheduling. However, in the case of unfair sharing of the radio resources and strict latency requirements, such scheduling methods are unsuitable. In [9], a cumulative distribution function based on the proportional fair scheduling scheme is proposed. The scheme allocates to the users high transmission power while their average rates achieve their peak rates. Delay-aware downlink scheduling schemes for OFDMA-based systems are proposed in [10] and [11], respectively. These schemes define the user with the highest priority based on the current channel conditions and the amount of queuing delay for real-time or non-real-time services. Furthermore, Ramli et al. [11] took into account packet loss tolerance as another constraint in their priority function definition. In this way, the packet loss of delay-sensitive applications is kept below a threshold. Comsa et al. in [12], propose a Q-learning based scheduling scheme that enables fair throughput provision for different classes of users.

However, most of the previous works do not consider the characteristics of the devices used at the end-user side. The improvements in the device display resolution together with the

limitation of the batteries lifetime, restrict the long-term use of the mobile devices. Therefore, this paper proposes a novel Utility-based Priority Scheduler (UPS) based on to the device display resolution, device energy consumption and estimated QoS requirements of the transmitted video stream.

III. UTILITY-BASED PRIORITY SCHEDULING MECHANISM

A. LTE Architecture Overview

The LTE network architecture includes two parts: Evolved Universal Terrestrial Radio Access (E-UTRA) and the Evolved Packet Core (EPC). The E-UTRA provides downlink/uplink interface for User Equipment (UE), such as smartphones, laptops or tablets. The EPC structure consists of Evolved Node B (eNodeB), gateways (e.g. Serving GW/PDN GW) and core network (e.g. Internet) which is based on all-IP architecture. For the downlink transmission the Orthogonal Frequency-Division Multiple Access (OFDMA) is exploited. The unit of OFDMA is the Resource Block (RB) which contains 12 consecutive subcarriers of 180 kHz bandwidth in the frequency domain, and

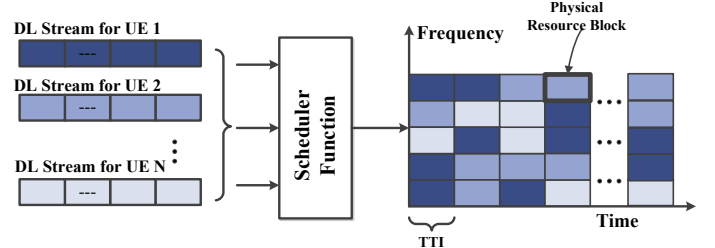


Figure 2. The Resource Allocation Strategy

in the time domain it accounts for 0.5 millisecond time slot [13]. Two consecutive RBs (referred to as Physical Resource Block (PRB) in this work) are assigned to a user for a Transmission Time Interval (1 millisecond). Moreover, a brief description of downlink resource allocation strategy over OFDMA is illustrated in Figure 2. Considering a number of N UEs

competing for resources, by using a scheduler function, each UE will get allocated PRBs on the physical channel in the time-frequency domain based on some specified conditions, such as channel states, QoS requirements or fairness conditions.

B. Framework of the proposed Scheduling Mechanism

The framework of the proposed solution is illustrated in Figure 3. The **Utility-based Priority Scheduling Mechanism** is distributed and consists of server-side, eNodeB-side and mobile client-side components.

At the Mobile Client-side the UEs are represented by LTE compatible devices and they are attached to eNodeB. The UEs integrate several functional blocks, such as: the Utility Weights Configuration block, which allows the user to set his preferences towards energy savings or required video quality level, and sends the utility weights to the eNodeB; the Device Characteristics block which provides information about the device resolution; the Energy Monitor block which provides information about the energy consumption of the mobile device, the QoS Monitor which provides information about the packet loss ratio; and the Network Monitor which provides the Channel Quality Indicator (CQI) Reports. According to the standard [14], the CQI reports could contain aperiodic CQI or periodic CQI by using the Subband or the Wideband, respectively. The proposed mechanism makes use of the Subband aperiodic CQI. Consequently, each UE collects CQI information on each physical resource block and sends this CQI Report to eNodeB together with Display Information, Energy Information and QoS Information. This information is sent periodically at every Transmission Time Interval (TTI).

The Server-side integrates the Quality-oriented Adaptation Scheme (QOAS) [15] which adaptively transmits the multimedia streams. The server either stores different quality levels (e.g., N levels) of the pre-recorded multimedia streams, from lowest (e.g., level 1) to highest (e.g., level N) or is able to transcode existing multimedia content into any of the N quality levels. Based on the feedback received from eNodeB, QOAS adjusts the data rate dynamically.

The core of the proposed mechanism Utility-based Priority Scheduler (UPS) is located at the eNodeB-side between the OSI MAC and physical (PHY) layers. UPS can be divided into two main conceptual phases: utility-based prioritization and resource allocation.

The **Utility-based Prioritization** phase consists of several functional blocks as illustrated in Figure 3: The *Device Display Classification* block makes use of the device resolution information in order to compute the Display Utility; the *Device Energy Control* block which makes use of the device energy consumption information in order to compute the Energy Utility; the *QoS Control* block which makes use of the device QoS information in order to compute the QoS Utility; and the *Utility-based Priority Function* block makes use of a multiplicative utility function in order to compute the priorities of the service requests based on the Display Utility, Energy Utility, QoS Utility, and the information about the buffer state. This information is then used in order to provide priority-based dynamic scheduling.

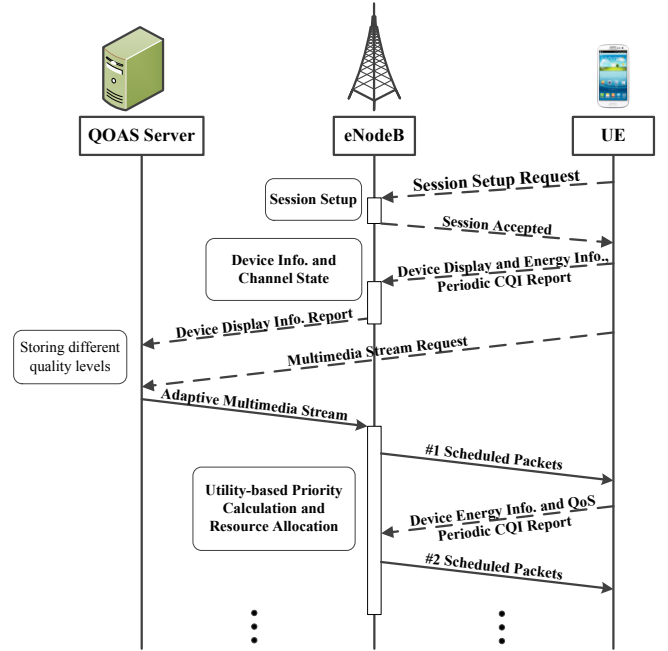


Figure 4. Message Flow Exchange of the Proposed Scheduling Mechanism

The **Resource Allocation** phase is triggered once the utilities for all UEs are calculated. The UE with the largest utility will be prioritized resulting in higher bandwidth share to be allocated to it. In order to do this, the Physical Resource Blocks (PRBs) with the highest bit rate located in the buffer will be mapped to the highest priority user in each TTI.

C. Message Flow Exchange of the proposed Scheduling Mechanism

In order to illustrate how the proposed scheduling mechanism works, a sequence diagram of the message flow exchange is illustrated in Figure 4. Initially, the UE sends a Session Setup Request to the eNodeB. Once the session request is accepted, the UE sends information about the display and the energy consumption of the mobile device to the eNodeB. The scheduler located at the eNodeB makes use of this information in order to classify the UE devices and assign priorities. The resource allocation is then done based on the computed priorities, such as the devices with higher priority will get more resources. Additionally, the UE will start sending the CQI reports to eNodeB as well. The Multimedia server integrates the QOAS mechanism which based on the received feedback adapts the multimedia stream dynamically. In the eNodeB, the scheduler assigns the prioritized PRBs to physical channel and transmits them to UEs. Afterwards, the QoS reporting per TTI for transmission starts.

D. Utility Function

Previous studies [16] have shown that the received bandwidth can be mapped to the user satisfaction for multimedia streaming applications by making use of utility functions. According to the principle of the proposed scheduling mechanisms, the scheduler makes use of the attribute of devices display, energy consumption rate and QoS of the multimedia stream transmission to prioritize the resource allocation. However, these three criteria are based on different range of values and

unit of measurement and need to be normalized through the use of utility functions. We propose an overall utility function based on the multiplicative exponential weighted (MEW) [17] method as given in equation (1):

$$U^{i,j}(t) = [u_r^{i,j}(t)]^{w_r} * [u_e^{i,j}(t)]^{w_e} * [u_{plr}^{i,j}(t)]^{w_{plr}} \quad (1)$$

where U is the overall utility for stream j of UE i at current scheduling instant t . $u_r^{i,j}$, $u_e^{i,j}$ and $u_{plr}^{i,j}$ are the utility functions for resolution of device display, energy and packet loss ratio for UE i , stream j at instant t , respectively. In addition, w_r , w_e and w_{plr} are the weights for those three criteria, and their sum is 1. The values for the weights can be defined by the user in the Utility Weights Configuration block as illustrated in Figure 3.

The overall utility is calculated for each UE, and the UE with the highest score will have assigned the highest priority.

1) Display Utility

In order to ensure good quality of experience to the mobile user, the multimedia stream should be played out on a display with an adequate resolution. Additionally, there are other factors that may impact the quality of the video, such as the available bandwidth, the performance of the receiver, etc. As various devices have different characteristics and hence different multimedia stream requirements, we take into account the device resolution when deciding on the device priority. For example, if the device resolution is high, the scheduler will assign a higher priority and the multimedia server will select a high quality level for the multimedia stream. According to the classification in [18], we define the display utility based on the different range of resolutions as illustrated in Table I.

TABLE I.
UTILITIES OF DISPLAY RESOLUTIONS

	Level 1	Level 2	Level 3	Level 4	Level 5
Resolution	$\geq 1024 \times 768$	(1024×768, 768×480]	(768×480, 480×360]	(480×360, 320×240]	$< 320 \times 240$
$u_r^{i,j}(t)$	1	0.75	0.5	0.25	0
	Excellent	Good	Acceptable	Poor	Unacceptable

2) Energy Utility

Depending on the device type and characteristics, as well as the network condition and the type of application, the estimated energy consumption ratio for UE i can be described as in equation (2) [19].

$$e_{i,j} = \frac{r_d \cdot D_{i,j} + r_t \cdot \mu + c}{E_c} \quad (2)$$

where D_j is amount of data of stream j of UE i required to transmission (Mbit), r_d is the energy consumption rate over transmitted data (Joule/Mbit), r_t is the energy consumption rate while the UE device is on standby status per unit of time (Watt), μ is the transaction time or the duration of the multimedia stream (e.g. length of video clip), c is the constant, and E_c is the current residual energy capacity of the UE device. The energy states are reported to the scheduler periodically.

Generally, smaller energy consumption ratios are more preferable. Therefore, the energy consumption utility is defined as below:

$$u_e^{i,j}(t) = \begin{cases} 1 & , e_{i,j} \leq e_{\min} \\ \frac{e_{\max} - e_{i,j}}{e_{\max} - e_{\min}} & , e_{\min} < e_{i,j} < e_{\max} \\ 0 & , \text{otherwise} \end{cases} \quad (3)$$

where e_{\max} is the maximum energy consumption ratio and e_{\min} is the minimum energy consumption ratio among the UEs.

3) QoS Utility

The study presented in [20] and [21] shows that the quality of the received videos (encoded with H.264 and MPEG 2) over IP networks have an acceptable user perceived quality if the packet loss ratio is lower than 2%. Based on this, and making use of the packet loss ratio classification from [18], the QoS Utility is illustrated in Figure 5. The QoS utility is represented by a s-shape curve which describes the tolerance of the multimedia streams to the packet loss ratio. We define five levels for the impact of the packet loss rate on the quality of the multimedia stream quality.

It is noteworthy that plr_{\min} (e.g. 0.1%) is the essential packet

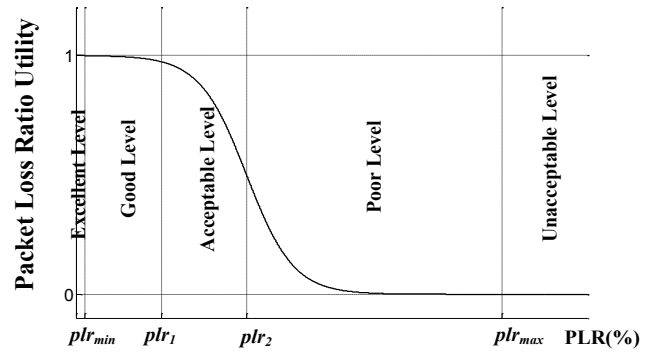


Figure 5. Packet Loss Ratio Utility

loss ratio tolerance for the multimedia stream with excellent quality. And if the packet loss ratio goes above plr_{\max} (e.g. 5%), the quality of the multimedia stream becomes unacceptable. In addition, good level and acceptable level of the multimedia quality are defined by plr_1 (e.g. 1%) and plr_2 (e.g. 2%), respectively.

Since low packet loss represents better quality for the multimedia stream, we consider the shape of the QoS utility to be concave as the packet loss ratio increases. Therefore, the equation of the s-shape curve for stream j of UE i at instant t is given as below:

$$u_{plr}^{i,j}(t) = \begin{cases} 1 & , plr \leq plr_{\min} \\ 1 - \frac{1}{1 + e^{-\alpha \times plr_{i,j}(t) - \beta}} & , plr_{\min} < plr_j < plr_{\max} \\ 0 & , plr \geq plr_{\max} \end{cases} \quad (4)$$

$$plr_{i,j}(t) = \frac{\sum_{t-w}^t Loss_{i,j}}{\sum_{t-w}^t Transmitted_{i,j}} \quad (5)$$

where $\alpha > 0$ and $\beta > 0$ determine the slope and the location of the reflection point of the function, respective. In equation (5), $plr_{i,j}$ represents the packet loss ratio of stream j of UE i measured during the transmission window w , $Loss_{i,j}$ is the packet loss (bytes) of stream j measured in UE i during the transmission window and $Transmitted_{i,j}$ is the amount of data (bytes) of stream j transmitted to UE i .

E. Utility-based Priority Scheduling Scheme

Using equation (1), the overall utility for all the UEs with active multimedia stream in the scheduling buffer is calculated. Then by using the Utility-based Priority Scheduling function defined in equation (6), the priorities of the streams with respect to UEs are computed.

$$P^{i,j}(t) = \overline{Th^{i,j}}(t) * U^{i,j}(t) \quad (6)$$

where $P^{i,j}(t)$ is the priority of the multimedia stream j for UE i at scheduling instant t , and $\overline{Th^{i,j}}(t)$ (see Eq. 6) is the average instantaneous rate of the multimedia stream j of UE i over all the unallocated physical resource blocks.

$$\overline{Th^{i,j}}(t) = \frac{\sum_{m \in M_{URB}(m,t)} C^{i,j}(m,t)}{|M_{URB}(m,t)|} \quad (7)$$

where $M_{URB}(m,t)$ is the set of the unallocated physical resource blocks at scheduling instant t in the buffer, and $C^{i,j}(m,t)$ is the instantaneous rate of stream j of UE i with

Algorithm 1 Utility-based Priority Scheduling Scheme

$t = 0$

WHILE(1)

FOR $i = 1$ **TO** No. of UEs **DO**

FOR $j = 1$ **TO** No. of Streams of UE i **DO**

calculate $u_r^{i,j}(t)$ at instant t , according to Table I

calculate $u_e^{i,j}(t)$ at instant t , according to Eq. (3)

calculate $plr_{i,j}(t)$ at instant t , according to Eq. (5)

calculate $u_{plr}^{i,j}(t)$ at instant t , according to Eq. (4)

WHILE $|M_{URB}(m,t)| > 0$ **DO**

calculate $\overline{Th^{i,j}}(t)$ at instant t , according to Eq. (7)

calculate $U^{i,j}(t)$ at instant t , according to Eq. (1)

calculate $P^{i,j}(t)$ at instant t , according to Eq. (6)

END WHILE

END FOR

END FOR

$i^* = \arg \max P^{i,j}(t)$

$m^* = \arg \max C^{i,j}(m,t)$ where $m \in M_{URB}(m,t)$

The Physical Resource Block m^* will be scheduled

$t = t + TTI$

END WHILE

physical resource block m at instant t .

According to the priority function described above, the highest priority is given to the stream j of the UE i which has both the highest priority and the highest average instantaneous rate. A pseudo-code of the proposed utility-based priority scheduling scheme is shown in Algorithm 1.

IV. NUMERIC EXAMPLE-BASED ANALYSIS

In this section, we define a simple scenario to analyze the proposed scheduling scheme and present a series of numerical results to see how the scheduler works. As shown in Table II, we assume a set of parameters for five different types of mobile devices. The weights of the different utilities are depending on user requirements.

TABLE II.
PARAMETERS OF DEVICE TYPES

	Type 5	Type 4	Type 3	Type 2	Type 1
Resolution	120×180	320×240	480×360	768×480	1024×768
E_c [Watt]	2000	4000	5920	7770	48000
r_d [Joule/Mbit]	0.05	0.10	0.10	0.20	0.40
r_t [W/s]	0.001	0.002	0.002	0.005	0.020
c	0.0	0.0	0.0	0.0	0.0
w_r	0.2	0.2	0.3	0.4	0.4
w_e	0.4	0.4	0.3	0.2	0.2
w_{plr}	0.4	0.4	0.4	0.4	0.4

If the five devices request the same content video, the QOAS server first receives the classification of request service from eNodeB, and then it delivers the videos encoded at five different quality levels, depending on the resolutions of these five devices. The formats and QoS requirements of these video delivery sessions are illustrated in Table III.

TABLE III.
CLASSIFICATION OF THE REQUESTED VIDEO AT THE QOAS SERVER

		Class 5	Class 4	Class 3	Class 2	Class 1
Video	Resolution	120×180	320×240	480×360	768×480	1024×768
	Bitrate [kbps]	120	240	480	960	1920
	Length [s]	100				

TABLE IV.
PRIORITY FOR DIVERSE DEVICE TYPES

	Type 5	Type 4	Type 3	Type 2	Type 1
u_r	0.00	0.25	0.50	0.75	1.00
u_e	1.000	0.277	0.374	0.000	0.737
u_{plr} ($\alpha=2.418$, $\beta=4.436$)	1	1	1	1	1
Overall U	0.000	2.356	2.557	0.000	2.941
P	0.0	565.4	1227.3	0.0	1618.6

The proposed scheduler computes the default QoS utilities by using the packet loss ratio values required for the five quality level video deliveries, respectively. The values of the utilities

are shown in Table IV after calculations employing equations (1)-(4). Additionally, we assume the transmission between the server and the eNodeB as being error free and the channel state of UEs as good enough, and therefore CQI and the modulation scheme are at the highest levels. The average instantaneous rate of the scheduled multimedia stream delivered to the UE equals to the bit rate of the multimedia stream.

It can be seen in Table IV how the highest priority is given to Type 1 device because the utilities of the resolution and packet loss ratio tolerance are the highest. Type 3 device gets the second highest priority due to the fact that its energy model is more efficient than that of Type 4 devices. Type 2 and Type 5 devices get the lowest priority.

V. SIMULATION ENVIRONMENT

In this section, we describe the simulation environment for the proposed scheduling mechanism. First of all, we assume the CQI reporting are error free and that equal downlink transmitting power is allocated to each Physical Resource Block. A brief illustration of the simulation scenario is presented in Figure 6. The scenario involves a QOAS server, one eNodeB and several different types of UEs.

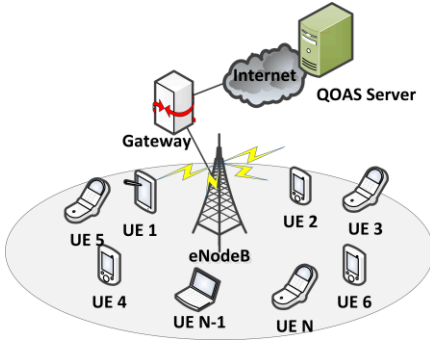


Figure 6. Simulation Topology and Scenario

We make use of the LTE-Sim [22] for the simulation platform, and the parameters of simulator configuration are listed in Table V. The simulation scenario consists of a 250 meter single cell with 1 eNodeB serving a varying number of UEs (e.g., from 10 to 150) with random distribution. These UEs are divided into five different types according to Table II. Based on the UPS mechanism the QOAS server will adapt between five quality levels video streams when transmitting to the UEs. When UPS is not invoked, the highest bitrate video stream will be transmitted to all the UEs. The performance of the proposed scheduler UPS is compared against the Proportional Fair (PF) Scheduler and the M-LWDF scheduler [11], in terms of average system throughput, average packet loss ratio and average PSNR.

VI. SIMULATION RESULTS

Figure 7 and Figure 8 present the average throughput and packet loss ratio of the downlink video traffic over the whole system for various numbers of UEs. By using UPS mechanism the QOAS transmits different quality levels of the video stream to different UE types. When using PF or M-LWDF only the highest quality video stream is delivered to the UEs. Thus, the system throughput when using M-LWDF and PF tend to achieve

TABLE V.
SIMULATION PARAMETERS

Parameter	Value
eNodeB Configuration	1 eNodeB; Single Cell; Radius=250m
UEs Configuration	Min No.=10; Max No.=150; Interval=10; Random Direction; 3 km/h
Physical Configuration	Carrier frequency=2.0 GHz; Bandwidth=20 MHz; Cyclic prefix=7 Symbols; Modulation: QPSK, 16QAM, 64QAM; Transmission Mode: SISO
Path Loss Model	Friis Propagation Model
Video Traffic Model	Five Quality Levels (Bitrate: 1920kbps, 960kbps, 480kbps, 240kbps, 120kbps)
TTI	1 millisecond
t_w	10 TTIs

the maximum as the number of UEs is greater than 20 and 30 respectively. However, UPS achieves 10% increase in the system throughput with a 60% decrease in packet loss ratio when the number of UEs reaches 70. Hence, UPS can accommodate a larger number of users and still provide increase in the system throughput and decrease in packet loss.

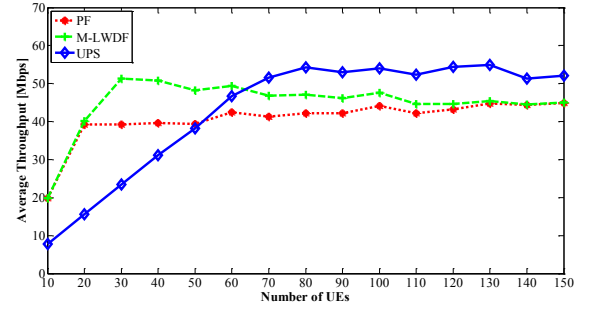


Figure 7. Average Throughput

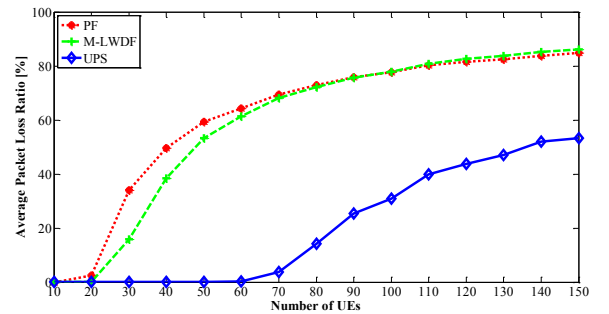


Figure 8. Average Packet Loss Ratio

In order to analyze the quality of received video stream, we make use of the Peak Signal-to-Noise Ratio (PSNR), based on an estimation method introduced in [23]. The PSNR estimation is given in equation (8).

$$PSNR = 20 \cdot \log_{10} \left(\frac{MAX_Bitrate}{\sqrt{(EXP_Thr - CRT_Thr)^2}} \right) \quad (8)$$

where $MAX_Bitrate$ is the average encoded bitrate of the video traffic, EXP_Thr is the average throughput expected to be achieved when delivering the adaptive video traffic and CRT_Thr is the actual measured throughput during the transmission.

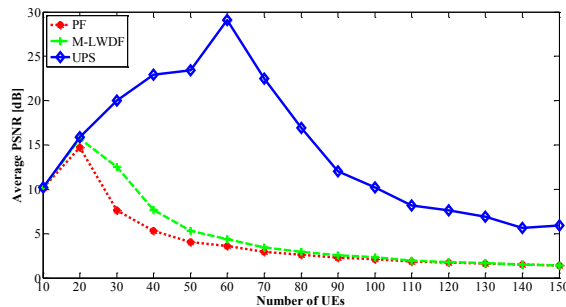


Figure 9. Average Video Quality

Figure 9 illustrates the average PSNR for various numbers of UEs and for each of the scheduling algorithms. For example in case of 60 UEs, there are improvements of 26dB and 24dB when using UPS in comparison with M-LWDF and PF, respectively. As the number of UEs is increasing, the competition for resource is increasing as well, however UPS provides a better video quality with respect to the other two scheduling schemes. This is because of the joint usage of the scheduling algorithm and adaptive multimedia server.

VII. CONCLUSION

This paper has proposed a Utility-based Priority Scheduling (UPS) mechanism for video delivery in LTE downlink systems. The proposed solution makes use of the device display resolution and energy consumption rate of the mobile device to efficiently allocate the resources for the transmission channel. The simulation results show how the proposed UPS algorithm accommodates a higher number of UEs while providing good quality levels within a single cell in comparison with other existing solutions such as M-LWDF and PF. Future work will consider the scheduling buffer delay and the fairness between different service types.

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